

3.23 MTI Clutter Rejection Sensitivity Analysis

MTI is generally configured as one or more delay-line cancelers which are connected in series. The ideal single delay-line canceler operates as follows: A received pulse signal, delayed by one pulse repetition interval, is compared with the next incoming received pulse signal. If the signal return is from a stationary target, such as clutter, the signals cancel; if the signals are reflected from a moving target, the signals are coherently integrated, leaving a residue which is the sum of the two target-reflected signals.

The delay line canceler can be considered as a comb filter having the following response:

$$G(f) = 2 \sin \frac{f_d}{PRF}^{2n} \quad (3.23-1)$$

where f_d = Doppler frequency of the return
 PRF = pulse repetition frequency of the radar
 n = number of cancelers

As can be noted from the above response function, at doppler frequencies which are multiples of the PRF, the signal attenuation is a maximum. This results in doppler blind speeds which occur when the relative aircraft velocity is such that the doppler frequency is a multiple of the PRF. At these aircraft velocities, the target signal is severely attenuated by the MTI filter and the target may not be detected.

In order to decrease the impact of doppler blind speeds upon target detection, the pulse repetition frequency is staggered, generally at each signal integration interval, such that the blind speed changes for each PRF interval. PRF staggering results in a somewhat different MTI filter response. The MTI response function of a single delay-line canceler for a staggered PRF pair is expressed as:

$$G(f) = 2 - \cos \frac{2f_d}{PRF_1} - \cos \frac{2f_d}{PRF_2} \quad (3.23-2)$$

where f_d = doppler frequency of the return
 PRF_1, PRF_2 = staggered pulse repetition frequencies

ALARM uses the functions identified above to represent the MTI filter. The noise and clutter signals are assumed to have Gaussian frequency distributions such that the clutter and noise signal output from the MTI filter are calculated as the integrated signal level over the response of the MTI filter. The target signal is assumed to be a single spectral line. Therefore, the target signal

output from the MTI filter is simply the product of signal input times the amplitude response of the MTI filter at the signal doppler frequency.

The above equations for the response of MTI delay-line cancelers result in infinite attenuation of target signals occurring at doppler frequencies which are multiples of the pulse repetition frequencies. In real radars, because of imperfect implementation and pulse-to-pulse clutter signal amplitude fluctuations, there is a remaining clutter signal residue after clutter signal cancellation, resulting in a finite attenuation of the clutter signal. Similarly, pulse-to-pulse target signal fluctuations degrade the integration gain of the target signal relative to that of a train of constant amplitude signals such that the target signal response of the MTI delay-line filter is different than the idealized case represented by the above equations.

3.23.1 Objectives and Procedures

At the function level, the objective of the sensitivity analysis is to determine the impact of pulse-to-pulse target signal fluctuations on the signal gain of the MTI filter. The ALARM MTI function is considered sensitive to target signal fluctuations if the difference in MTI target signal gain for a fluctuating target relative to a non-fluctuating target is greater than 3 dB.

At the model level, the objective of the sensitivity analysis is to determine the impact of changes in MTI integration gain, due to pulse-to-pulse target signal fluctuations, on target detection range. ALARM is considered sensitive to signal fluctuations if the normalized mean difference in target detection range for a fluctuating target relative to a non-steady target signal is greater than 5.0%.

To conduct the sensitivity analyses, the ALARM MTI response algorithm was modified to accomodate random pulse amplitudes. In baseline ALARM, the algorithm is implemented by weighting the three pulses entering the MTI filter. The weights are 1.0, 2.0, and 1.0, which are multiplied by the amplitudes of the first, second, and third pulses, respectively. To create random pulse amplitudes, the weights were changed by substituting their values with pseudo-random draws from a uniform distribution.

For the function-level sensitivity analysis, ALARM is run in Flight Path mode, using the non-fluctuating pulse amplitude algorithm (baseline) and the modified version of the algorithm. The signal-to-interference ratio (S/I) is recorded at each flight path point for both model runs and compared.

At the model level, ALARM is run in Contour Plot mode using the two different algorithms. Initial target detection range is determined for each flight path offset for both model runs.

Table 3.23-1 identifies the specific parameters varied for these analyses.

Table 3.23-1 ALARM Runs for MTI Sensitivity Analyses

Sensitivity Parameter	Analysis Level	Input Variable	Range of Variation	Output Variable	Test Case Description
Target Signal Pulse Amplitude	FE	(Internal constants)	Amplitude weights = 1, 2, 1	SIGTOI	Run ALARM in Flight Path mode using the 2 MTI filter pulse amplitude algorithms. Record S/I at each flight path point, in both runs.
	Model		Amplitude weights = random	SIGTOI	Run ALARM in Contour Plot mode using the 2 MTI filter pulse amplitude algorithms. Determine initial detection range for each flight path offset for both runs.

3.23.2 Results

Figure 3.23-1 shows plots of the target S/I output from the MTI delay-line canceler vs. flight path point for both a steady and fluctuating target signal input. For a fluctuating target signal, the output signal level from the MTI canceler is always less than that for a steady signal input, and generally exceeds the 3.0 dB functional element significance threshold.

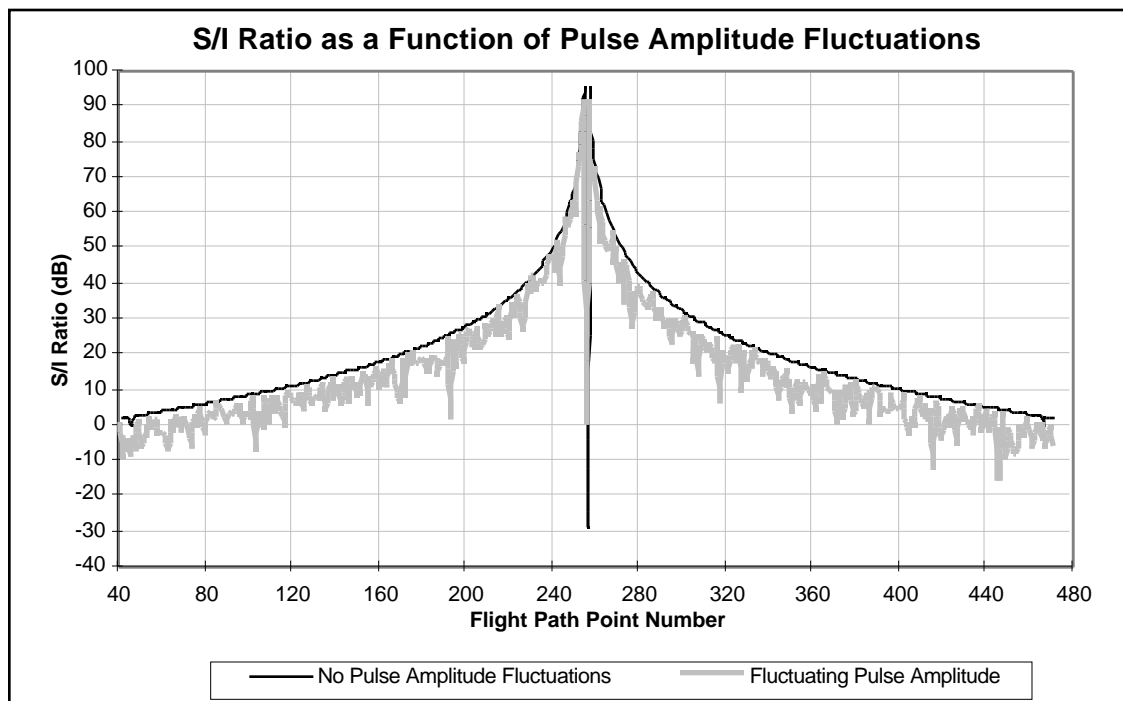


Figure 3.23-1 MTI Output Signal-to-Interference Ratio as a Function of Pulse Amplitude Fluctuations

Figure 3.23-2 plots the maximum target detection range vs. target offset range for both a steady and fluctuating target signal at the input to the MTI target filter. As can be observed, target detection generally occurs at greater ranges for a steady target signal relative to target detection of a fluctuating target. As shown in table 3.23-2, the normalized mean difference in target detection range is 11%, which exceeds the 5% sensitivity threshold. Although the target signal fluctuation distribution was arbitrarily chosen, the sensitivity of the MTI filter to target signal fluctuations indicates that the MTI response should be measured for actual target signals as well as steady, synthetically generated target signals.

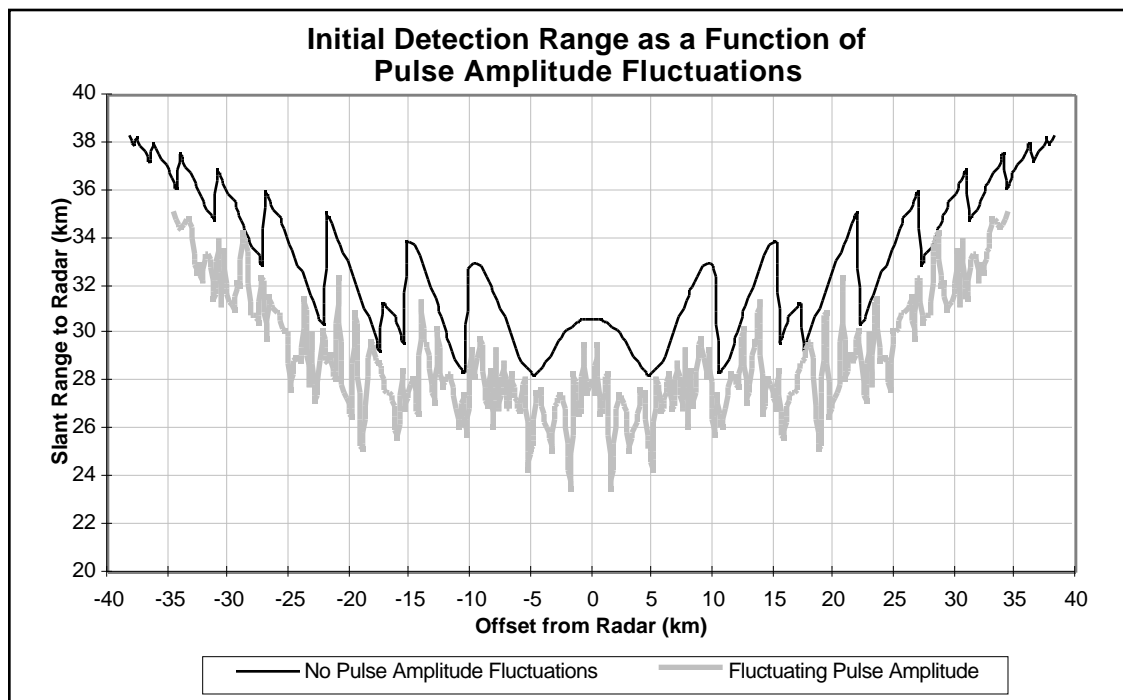


Figure 3.23-2 Target Detection Range vs Target Offset Range for Steady and Fluctuating MTI Input Signals

Table 3.23-2 Detection Range Statistics for MTI Sensitivity Analysis

Signal Fluctuation	Mean (m)	(m)	Normalized Mean Difference	% Change
Non-fluctuating (baseline)	32.82	2.84	-	-
Random pulse amplitudes	29.08	2.54	-0.060	-11.38

3.23.3 Conclusions

Although the algorithms used in the model to represent the MTI function may be valid for a steady target signal, it appears likely that there may be significant error in the modeled MTI response for fluctuating target signals. In collecting measured MTI response validation data, it will be essential to measure the MTI response for both fluctuating and steady target signals. If the measured response to fluctuating targets is significant, relative to the measured MTI response to a steady target, it may be advisable to characterize target fluctuations and modify the MTI model algorithms to more validly represent the MTI function.

The user should be aware of the potentially significant deficiency in the modeled MTI functional element. The significance of the differences in MTI response to a fluctuating target cannot be definitively determined without validation data. Because of the uncertainty in the significance of the model deficiency, there is a high priority for collecting validation data for this functional element.

